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GB 2329762 A **GB 2044550 A** **EP 0845792 A2**
JP 630318112 A **JP 040338613 A**

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INT CL[7] **H01F 3/10 17/00 17/04 27/02 27/24 27/255 27/34 27/36 37/00 41/00**
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(54) Abstract Title
An induction device

(57) An induction device, such as a reactor or transformer, comprises a winding 2 arranged around an elongate core 1 of magnetically permeable material. The core is encased in a body 3 which, at least in the regions of the ends of the core 1, comprises finely divided soft magnetic particles in a matrix of a dielectric material. In alternative embodiments, the core has a dog bone shape or comprises magnetic wires or ribbons.

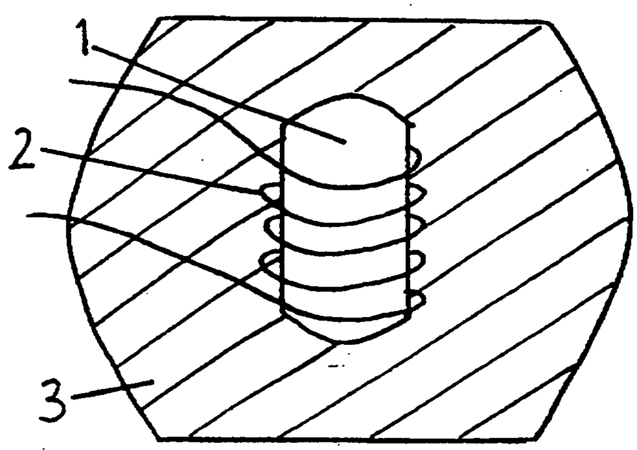

Fig. 1

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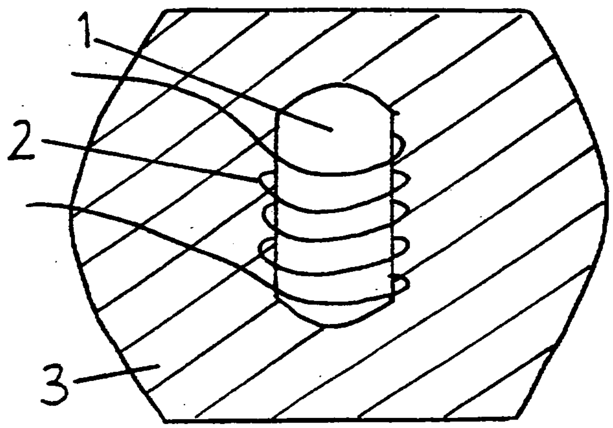

Fig. 1

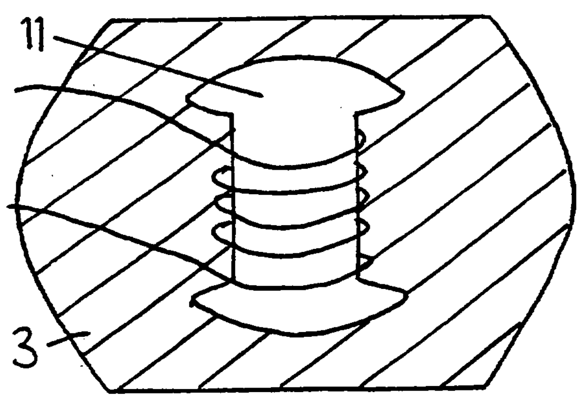

Fig. 2

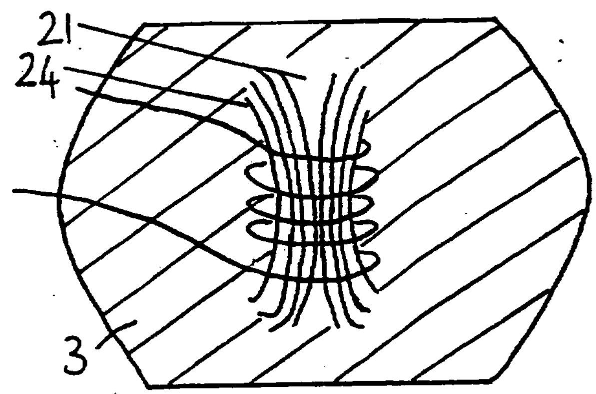

Fig. 4

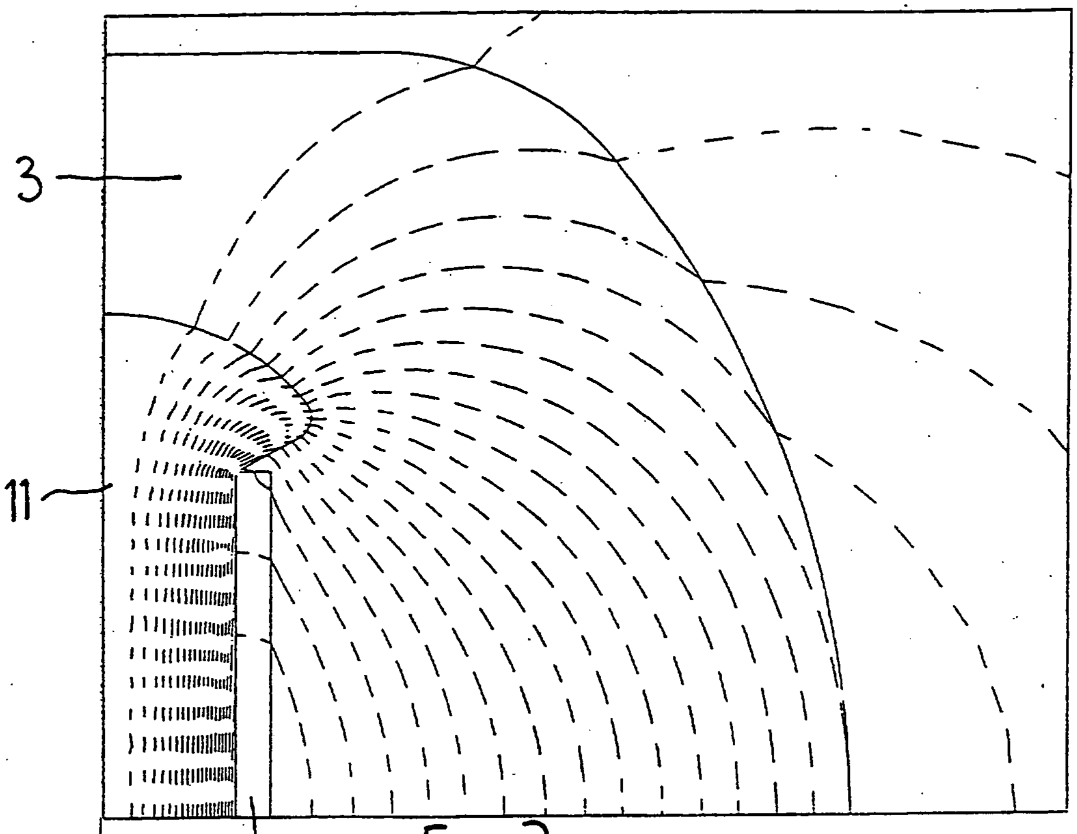

Fig. 3

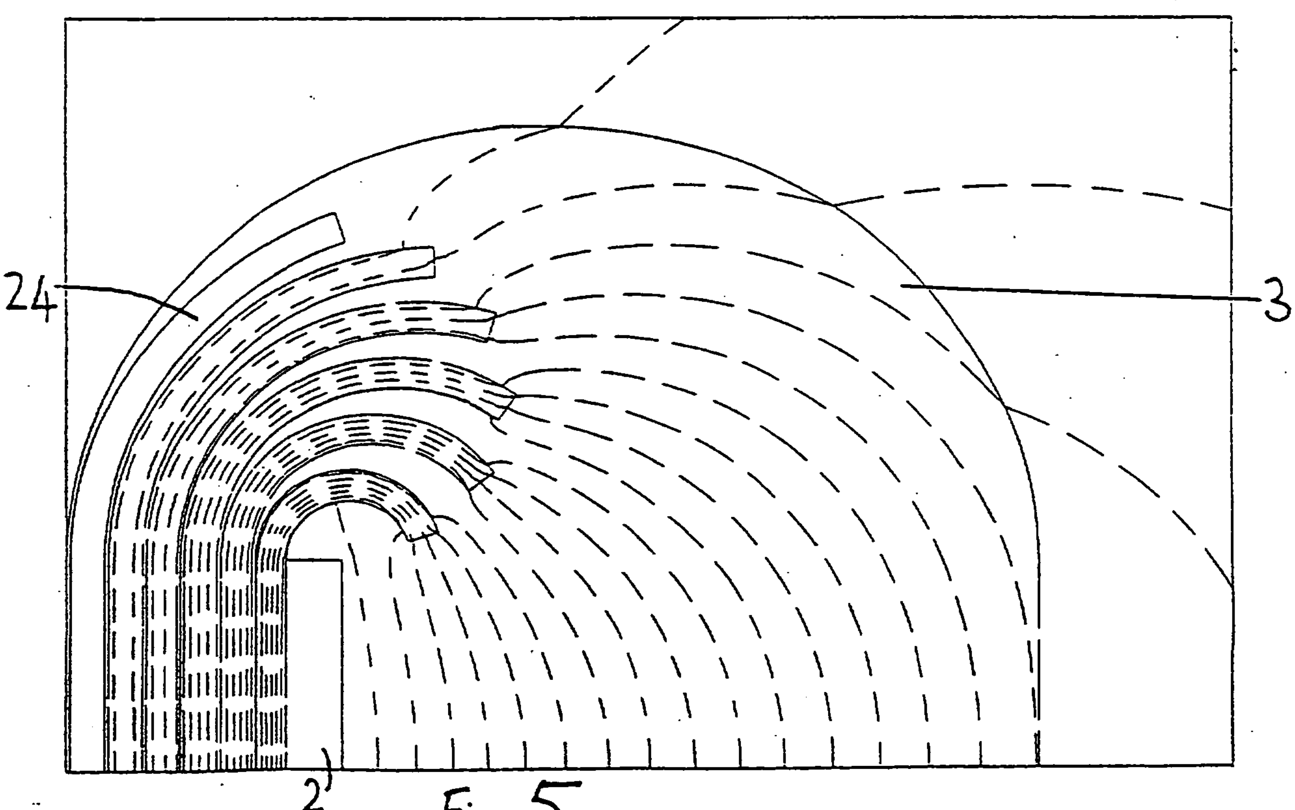

Fig. 5

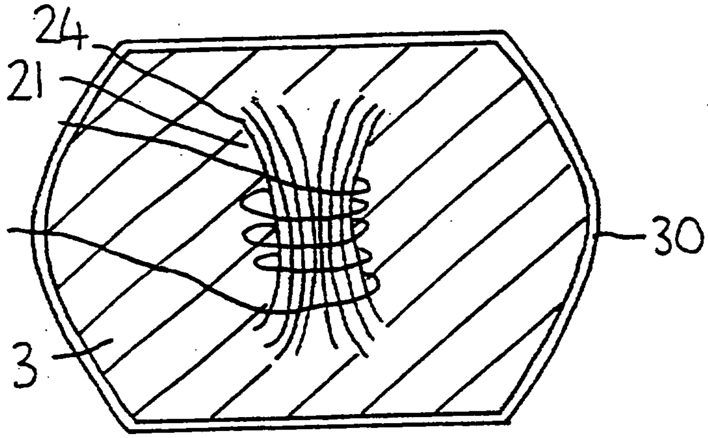

Fig. 6

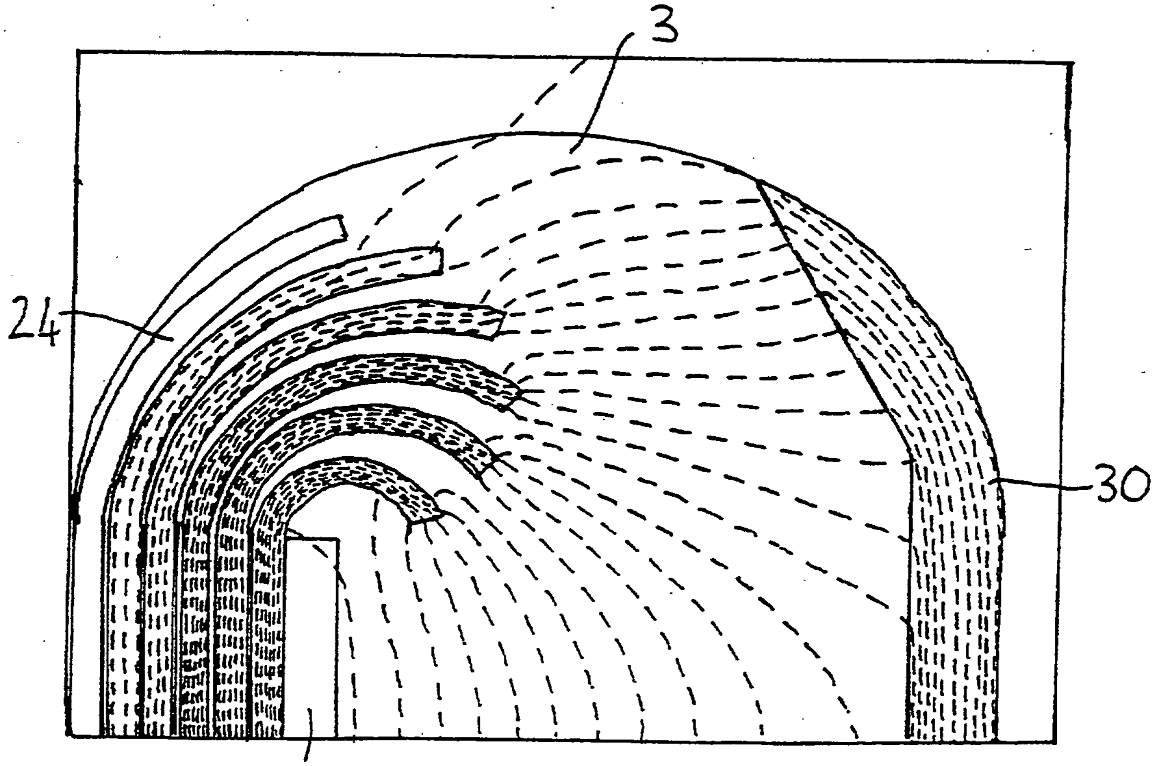

Fig. 7

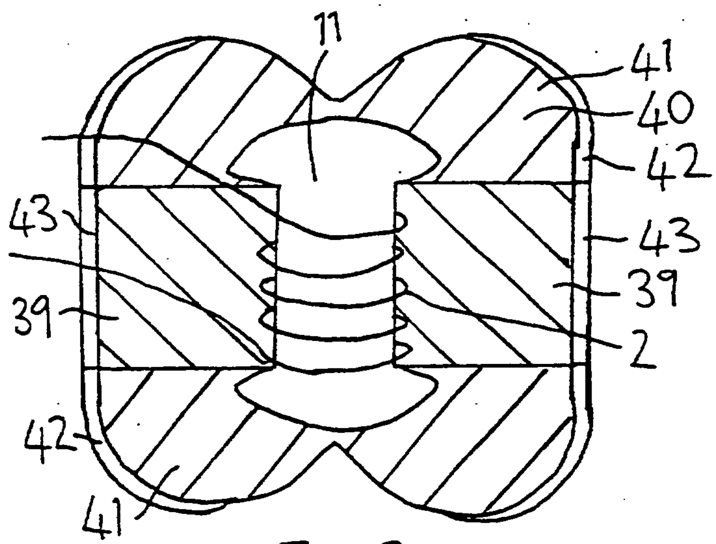

Fig. 8

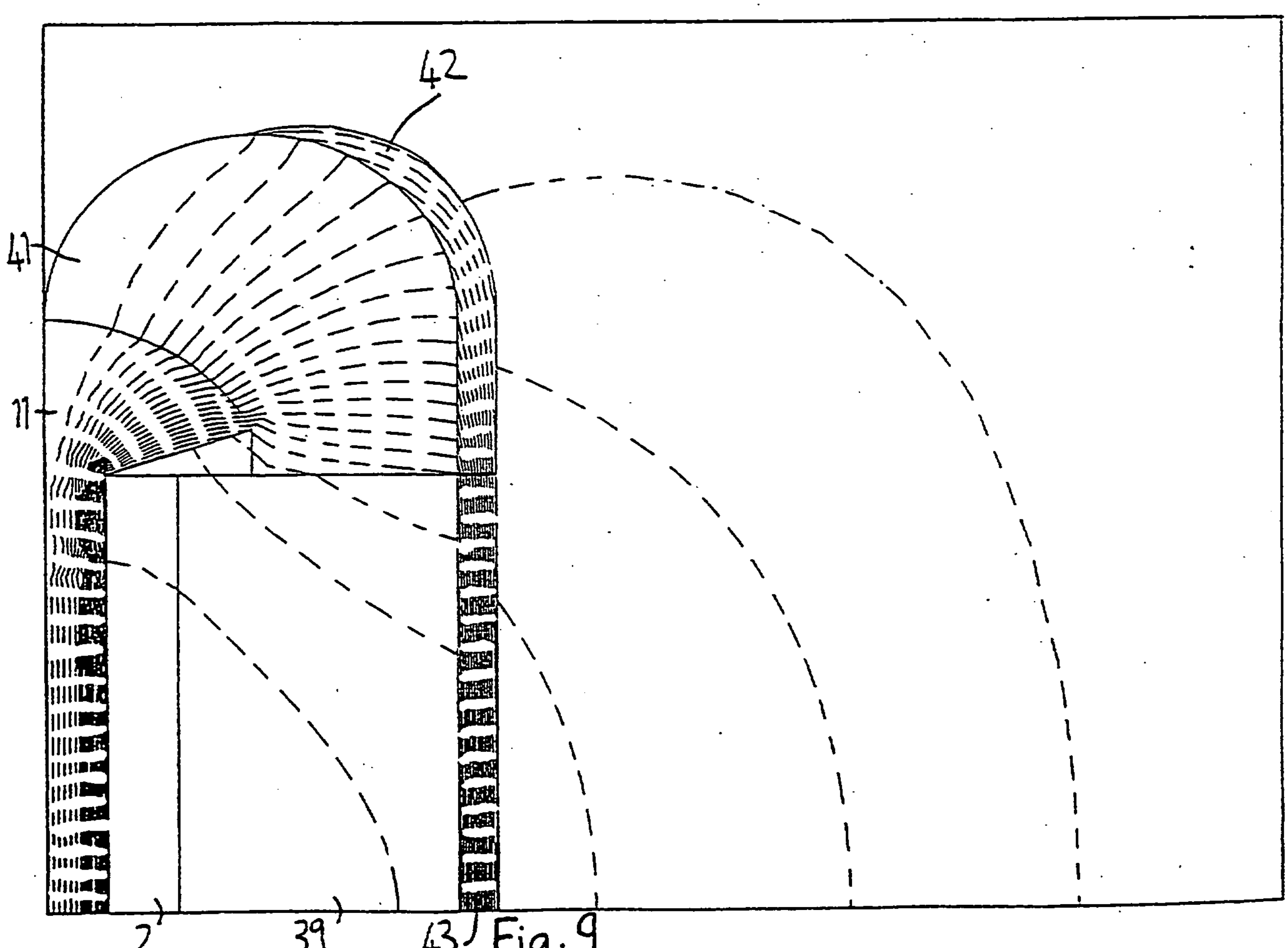

Fig. 9

AN INDUCTION DEVICE

Background to the invention

The present invention relates to an induction device, such as a reactor or transformer, having a magnetic core.

The invention is particularly applicable to a large reactor for use in a power system, for example in order to compensate for the Ferranti effect in long overhead lines or extended cable systems causing high voltages under open circuit or lightly loaded conditions. Reactors are sometimes required to provide stability to long line systems. They may also be used for voltage control and switched into and out of the system during lightly loaded conditions.

Transformers are used in power systems to step up and step down voltages to useful levels.

A typical known induction device comprises one or more coils wrapped around a laminated core to form windings, which may be coupled to the line or load and switched in and out of the circuit. The equivalent magnetic circuit of a static induction device comprises a source of magnetomotive force, which is a function of the number of turns in the winding, in series with the reluctance of the core, which may include iron and optionally an air gap.

The air gap represents a weak link in the structure of the core, which tends to vibrate at a frequency twice that of the alternating input current. This is a source of vibrational noise and high mechanical stress. Another problem associated with the air gap is that the magnetic field fringes, spreads out and is less confined. Thus, field lines tend to enter and leave the core with a non-zero component transverse to the core laminations which can cause a concentration in unwanted eddy currents and hot spots in the core.

It is known to alleviate these problems by placing one or more inserts in the air gap, for example comprising radially laminated steel plates and ceramic spacers. However, such inserts are complicated and difficult to manufacture and are therefore relatively expensive.

Summary of the invention

It is an aim of the invention to provide an induction device in which the effective permeability of the magnetic circuit is lowered, whilst avoiding the disadvantages of an air gap.

Accordingly, the present invention provides an induction device comprising a winding arranged around a core of magnetically permeable material, the core having ends, characterised in that the core is encased in a body which at least in the regions of the ends of the core, comprises finely divided magnetic particles in a matrix of a dielectric material. The magnetic particles may for example be of iron, amorphous iron based materials, or alloys such as Ni-Fe, Co-Fe, or Fe-Si, or ferrites based for example an at least one of manganese, zinc, nickel and magnesium (and preferably on an alloy such as Mn-Zn, Ni-Zn or Mn-Mg). They may have a size of about 1nm to about 1mm, preferably about 0.1μm to 200μm, and may optionally be coated with dielectric material, for example a metal oxide or other inorganic compound. The dielectric material of the matrix may be an epoxy resin, polyamide, polyimide, polyethylene, cross-linked polyethylene, polytetrafluoroethylene and polyformaldehyde sold under the trade mark "Teflon" by DuPont, rubber, ethylene propylene rubber, acrylonitrile-butadiene-styrene, polyacetal, polycarbonate, polymethyl methacrylate, polyphenylene sulphone, PSU, polyetherimide, PEEK or the like, concrete, foundry sand, or a fluid such as water or a gas.

As the body has a low magnetic permeability it performs the same function as the air gap of a known induction device but does not share the disadvantages of the air gap. At the

same time, the core has a high magnetic permeability, and thus the length of the winding can be reduced by a factor of up to 5 in comparison with a toroidal core formed from magnetic powder. The core is preferably formed from laminated electrical steel, but may be formed from highly compacted soft magnetic powder.

Preferably, the cross-sectional area of the body is such that its permeability is constant and leakage flux is reduced.

In a preferred embodiment of the invention, the body is surrounded by a shield of soft magnetic material so as to reduce leakage flux. A preferred material for the shield is compacted ferrite powder, such as Mn-Zn ferrite powder, since the high electrical resistivity and small particle size of the powder results in very small induced eddy currents.

In an embodiment of the invention, the core has the shape of an apple core or dog bone, with enlarged ends, when viewed in cross-section. This avoids flux concentration and guides the flux in an even distribution flux. A similar effect can be obtained by forming the core from magnetic wires or ribbons, which diverge at the ends of the core, instead of laminated electrical steel. The divergent wires or ribbons form a transition region of higher magnetic permeability than the bulk of the body. Such transition regions at or near the ends of the core can alternatively or additionally be formed by rasing the concentration of magnetic particles in the dielectric matrix in the desired regions.

A cost saving can be achieved by substituting a material having a magnetic permeability substantially equal to that of free space, such as concrete, for the dispersed magnetic powder in the part of the body not surrounding the ends of the core, i.e. the part surrounding the winding. This has the additional advantage that leakage flux through the winding is reduced. Furthermore, if an outer shield is provided, at the part of the body formed from material having a magnetic

permeability substantially equal to free space, the shield can be formed from electrical steel or an amorphous iron band, which materials are cheaper than compacted ferrite powder, since in that part of the body little flux penetration occurs.

Brief description of the drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a cross-sectional view of a reactor according to a first embodiment;

Figure 2 is a cross-sectional view of a reactor according to a second embodiment;

Figure 3 is a plot of magnetic flux lines for the reactor of Figure 2;

Figure 4 is a cross-sectional view of a reactor according to a third embodiment;

Figure 5 is a plot of magnetic flux lines for the reactor of Figure 4;

Figure 6 is a cross-sectional view of a reactor according to a fourth embodiment;

Figure 7 is a plot of magnetic flux lines for the reactor of Figure 6;

Figure 8 is a cross-sectional view of a reactor according to a fifth embodiment; and

Figure 9 is a plot of magnetic flux lines for the reactor of Figure 8.

Detailed description of the preferred embodiment

Figure 1 shows a reactor comprising a substantially cylindrical core 1 of laminated electrical steel around which is wound a conductor 2. The conductor preferably comprises a central conducting means surrounded in turn by a semiconducting layer, an insulating layer and a further semiconducting layer.

The core 1 is encased in a body 3 of finely divided magnetic particles in a matrix of dielectric material. The magnetic particles are of iron, amorphous iron based materials, or an alloy such as Ni-Fe, Co-Fe or Fe-Si, or ferrites such as those based on Mn-Zn, Ni-Zn or Mn-Mg, have a size from 0.1μm to 200μm and are optionally coated with dielectric material, for example a metal oxide or other inorganic compound. The dielectric material of the matrix is epoxy resin, polyamide, polyimide, polyethylene, cross-linked polyethylene, polytetrafluoroethylene, polyformaldehyde, rubber, ethylene propylene rubber, acrylonitrile-butadiene-styrene, polyacetal, polycarbonate, polymethyl methacrylate, polyphenylene sulphone, PSU, polyetherimide or PEEK, concrete or foundry sand or a fluid such as water or a gas. The core 1 has a relative magnetic permeability of several thousand and the body 3 has a relative magnetic permeability of between 1 and about 20.

The reactor of Figure 1 is simple to manufacture and has an even distribution of forces. In addition the design generally eliminates damaging vibration and problematic noise. The design also involves a reduced number of parts, allowing a more reliable and economic construction.

Figure 2 shows a modified reactor in which the steel core 11 has enlarged ends, resulting in a "dog bone" shape. This shape of core prevents concentrations of magnetic flux, guiding the flux in evenly distributed paths as shown by dotted lines in the finite element plot of Figure 3 which shows one quarter of the cross-section of the reactor.

Figure 4 shows an alternative reactor in which the same guidance and distribution of magnetic flux is achieved by forming the core 21 from magnetic wires or ribbons 24 instead of laminated electrical steel. Figure 5 is a finite element plot showing flux distribution in the reactor of Figure 4, and also showing how the ends of the magnetic wires are arranged. The magnetic wires are of different lengths. In the reactors of Figures 2 to 5, leakage flux through the coil is reduced, thereby reducing the eddy losses in the cable.

Figure 6 shows a further alternative reactor, also having a core 21 formed from magnetic wires 24. The reactor body 3 is encased in a shield 30 which may be formed from a compacted soft magnetic Mn-Zn-ferrite powder or a compacted iron-based powder with an optional inorganic dielectric coating. The shield greatly reduces the amount of magnetic flux leaking out from the reactor body. It has a relative magnetic permeability of about 1000, so that lines of magnetic flux run inside the shield 30 near one end of the reactor and back into the reactor body 3 at the other end.

The Mn-Zn-ferrite material has a relatively high electrical resistivity (about three to five orders of magnitude higher than electrical steel which is presently used as a magnetic flux shield in air-cored reactors) and this means that eddy current losses in the shield 30 are very low. Such losses will be higher if the shield is made from electrical steel or other highly electrically conductive material, as the magnetic flux induces eddy currents when it enters the shield almost at right angles.

Figure 7 is a finite element plot of the magnetic flux occurring in the reactor shown in Figure 6. It will be seen that lines of magnetic flux are concentrated in the shield 30 and flux leakage is reduced.

Whilst the material of the body of each reactor described above (sometimes referred to as a "distributed air-gap

material") achieves its function of allowing the reactor to operate in the linear region of the B-H curve (where B is magnetic flux and H applied field), it is a relatively expensive material. Figure 8 therefore shows an embodiment of the invention in which a portion 39 of a body 40 surrounding the winding 2 on the core 11 is made of concrete. As before, the ends 41 of the body 40 are made from the distributed air gap material. A composite magnetic field shield surrounds the reactor. The portions 42 of this shield enclosing the ends 41 of the body are of soft ferrite material such as the Mn-Zn-ferrite material mentioned above, whilst the central portion 43 of the shield is of electrical steel or an amorphous material of similar magnetic permeability to electrical steel. This central portion 43 can be formed by winding a strip of material on to the concrete portion 39 of the reactor body 40.

Figure 9 is a plot of magnetic flux lines (dotted) in the reactor shown in Figure 8. It will be seen that the low magnetic permeability of the concrete portion 39 (approximately equal to the permeability of free space) prevents magnetic flux leakage from the cables. At the same time, the steel portion 43 of the shield provides a path for the magnetic flux, and since that flux enters the shield portion 43 either parallel or nearly parallel to the axis of the reactor and portion 43, eddy currents therein are low.

The specific embodiments described above can be modified without departing from the scope of the appended claims. In particular, the reactors shown in Figures 6 and 8 could be provided with a core of simpler shape such as that shown in Figure 1. The concrete portion 39 of the reactor body shown in Figure 8 could instead be formed from any suitable material having a magnetic permeability similar to that of free space.

Multiphase (such as three-phase) embodiments of the invention can be manufactured by moulding a single reactor body around a plurality of wound cores.

CLAIMS

1. An induction device comprising a winding arranged around a core of magnetically permeable material, the core having at least two ends, characterised in that the core is encased in a body which at least in the regions of the ends of the core, comprises finely divided soft magnetic particles in a matrix of a dielectric material.

2. An induction device according to claim 1, characterised in that the core has two ends.

3. An induction device according to claim 1 or 2, characterised in that the magnetic particles comprise a material selected from the group consisting of iron, amorphous iron-based materials, alloys and ferrites.

4. An induction device according to claim 3, characterised in that the magnetic particles comprise an alloy selected from Ni-Fe, Co-Fe and Fe-Si.

5. An induction device according to claim 3, characterised in that the magnetic particles comprise a ferrite based on at least one of manganese, zinc, nickel and magnesium.

6. An induction device according to any preceding claim, characterised in that the magnetic particles have a size from about 1 nm to about 1 mm.

7. An induction device according to claim 6, characterised in that the magnetic particles have a size from 0.1 μm to about 200 μm.

8. An induction device according to any preceding claim, characterised in that the magnetic particles are coated with dielectric material.

9. An induction device according to any preceding claim, characterised in that the dielectric material of the matrix comprises an epoxy resin, polyamide, polyimide, polyethylene, cross-linked polyethylene, polytetrafluoroethylene, polyformaldehyde, rubber, ethylene propylene rubber, acrylonitrile-butadiene-styrene, polyacetal, polycarbonate, polymethyl methacrylate, polyphenylene sulphone, PSU, polyetherimide, PEEK, concrete, foundry sand or a fluid.

10. An induction device according to any preceding claim, characterised in that the magnetic particles are coated with a dielectric coating comprising an inorganic material.

11. An induction device according to any preceding claim, characterised in that the core is of electrical steel.

12. An induction device according to claim 11, characterised in that the core is laminated.

13. An induction device according to any one of claims 1 to 10, characterised in that the core is of highly compacted magnetic powder.

14. An induction device according to claim 10, 11 or 12, characterised in that the ends of the core are enlarged.

15. An induction device according to claim 14, characterised in that the core has a dog-bone shape.

16. An induction device according to any one of claims 1 to 10, characterised in that the core comprises magnetic wires or ribbons.

17. An induction device according to claim 16, characterised in that the magnetic wires or ribbons diverge at the ends of the cores.

18. An induction device according to claim 17, characterised in that the magnetic wires or ribbons are of different lengths.

19. An induction device according to any preceding claim, characterised in that the body includes transition regions comprising raised concentrations of magnetic particles at the ends of the core.

20. An induction device according to any preceding claim, characterised in that a portion of the body surrounding the winding is formed from a material having a relative magnetic permeability from zero up to approximately 1.

21. An induction device according to claim 20, characterised in that said material is concrete.

22. An induction device according to any preceding claim, characterised in that the body is surrounded by a shield of soft magnetic material.

23. An induction device according to claim 22, characterised in that said shield comprises compacted ferrite powder, at least in the region of the ends of the core.

23. An induction device according to claims 20 and 22, characterised in that a part of said shield surrounding the material having a relative magnetic permeability from zero up to approximately 1 comprises electrical steel or amorphous based iron.

The Patent Office

INVESTOR IN PEOPLE

Application No:	GB 0008155.4	**Examiner:**	John Watt
Claims searched:	1 - 23	**Date of search:**	14 August 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H1T (T7A1, T7A8, T7A2A, T7A2B, T15)

Int Cl (Ed.7): H01F 3/10, 17/00, 17/04, 27/02, 27/24, 27/255, 27/34, 27/36, 37/00, 41/00

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2329762 A	(TAIYO YUDEN) see figs.1 - 12	1 - 10, 13, 20 & 22
X	GB 2044550 A	(GEC) see fig.1 and page 1, line 95 to page 2, line 10	1 - 5, 9 & 13
X	EP 0845792 A2	(TAIYO YUDEN) see fig.4 and col.6, lines 20 - 38	1 - 3 & 9 at least
X	JP 040338613 A	(MURATA) see English abstract	1 - 3 & 9 at least
X	JP 630318112 A	(TDK) see English abstract	1, 2 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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